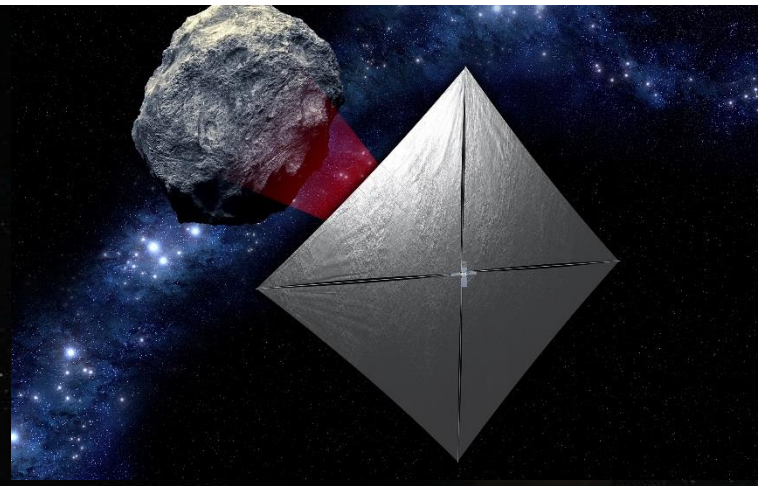
National Aeronautics and Space Administration

Status of Solar Sail Propulsion Within NASA

Moving Toward Interstellar Travel

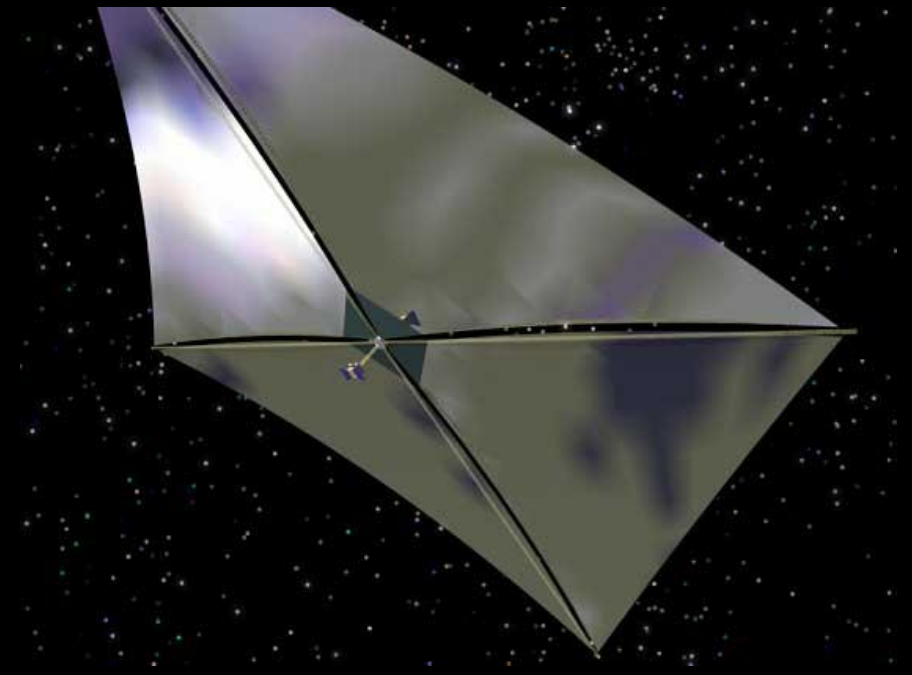


Les Johnson
NASA MSFC

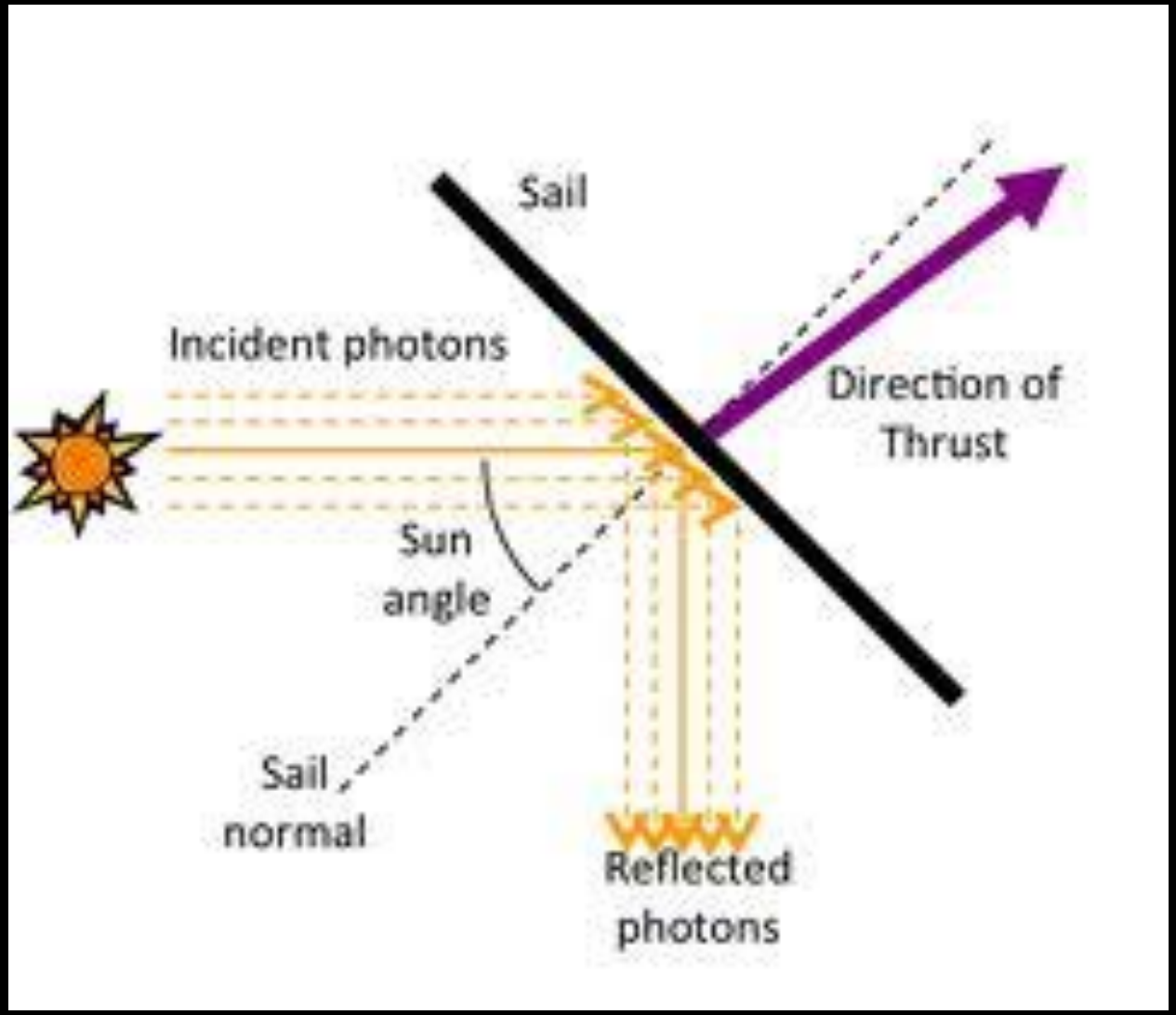
NASA and Solar Sails

- Solar Sails – What are they and how do they work?
- Planned Solar Sail Missions (NASA leading or partnering)
  - Near Earth Asteroid Scout
  - InflateSail
  - LightSail-B
- The BIG and Not-So-Secret Plan (Hint: Why we are at this symposium!)

How Does a Solar Sail Work?

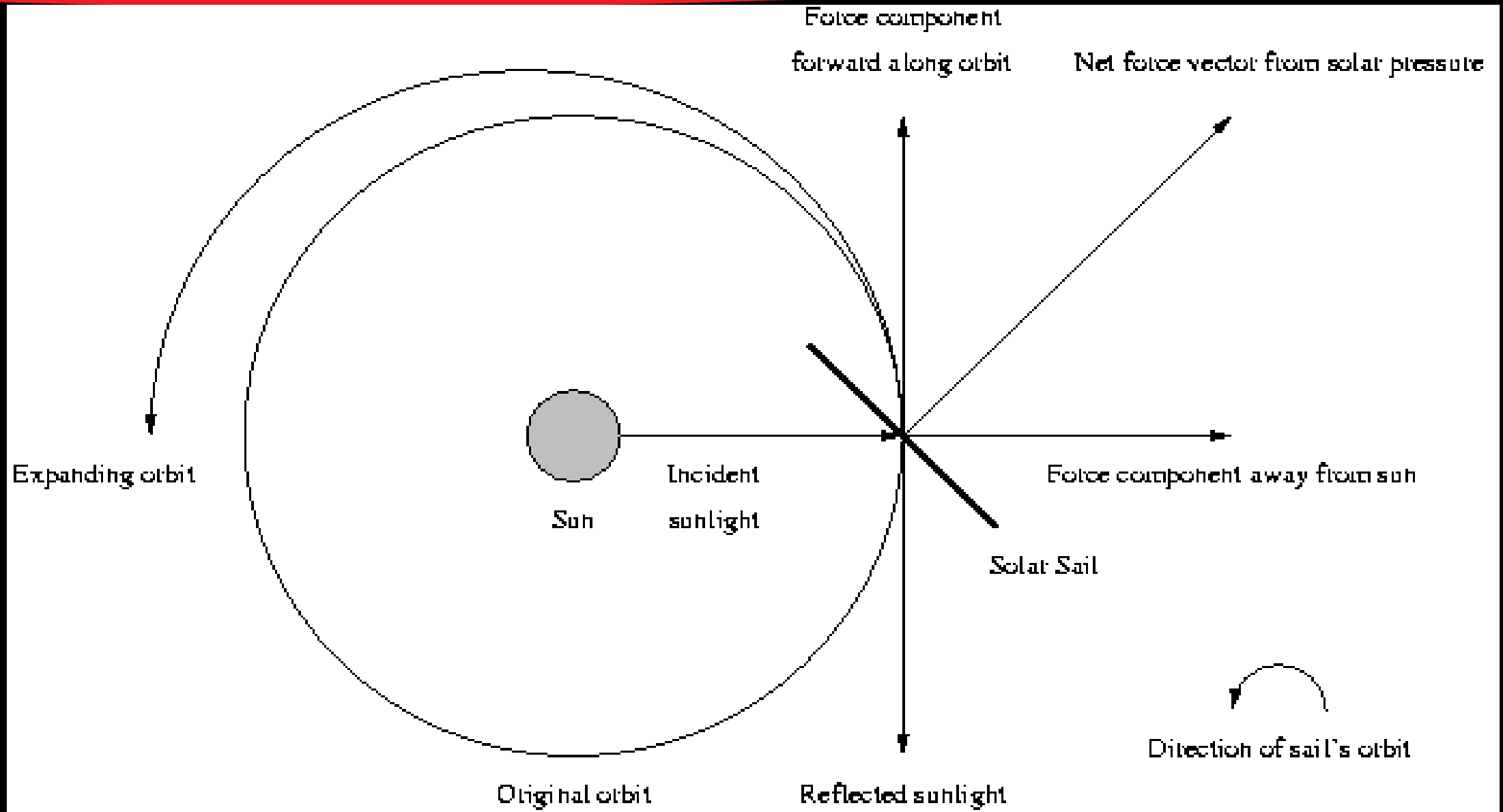


Solar sails use photon “pressure” or force on thin, lightweight reflective sheets to produce thrust.



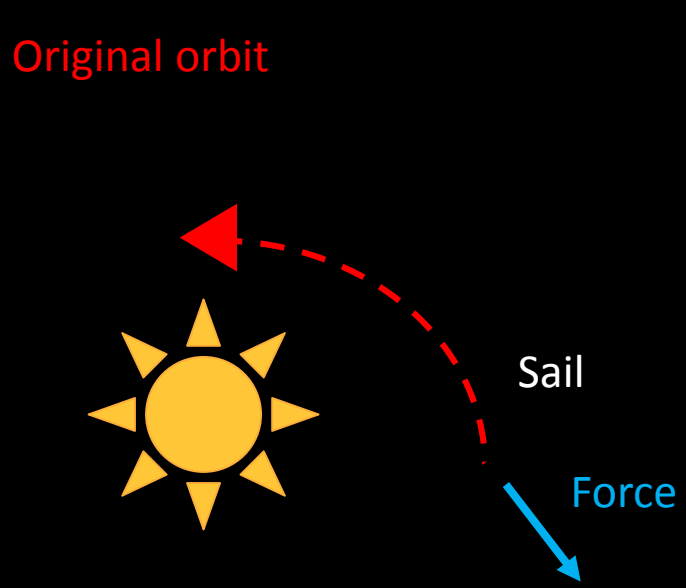
Solar Sails Can Spiral Inward or Outward From The Sun

Image courtesy of Colorado Center for Astrodynamics Research

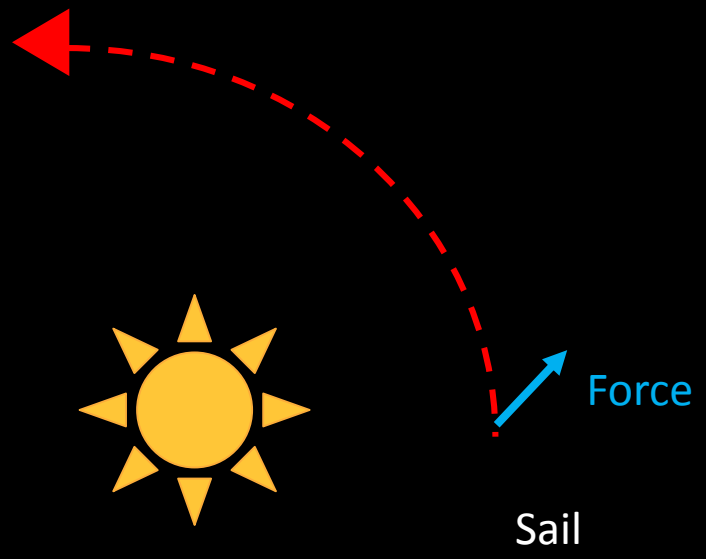


Solar Sail Trajectory Control

Solar Radiation Pressure: Inward and outward Spiral

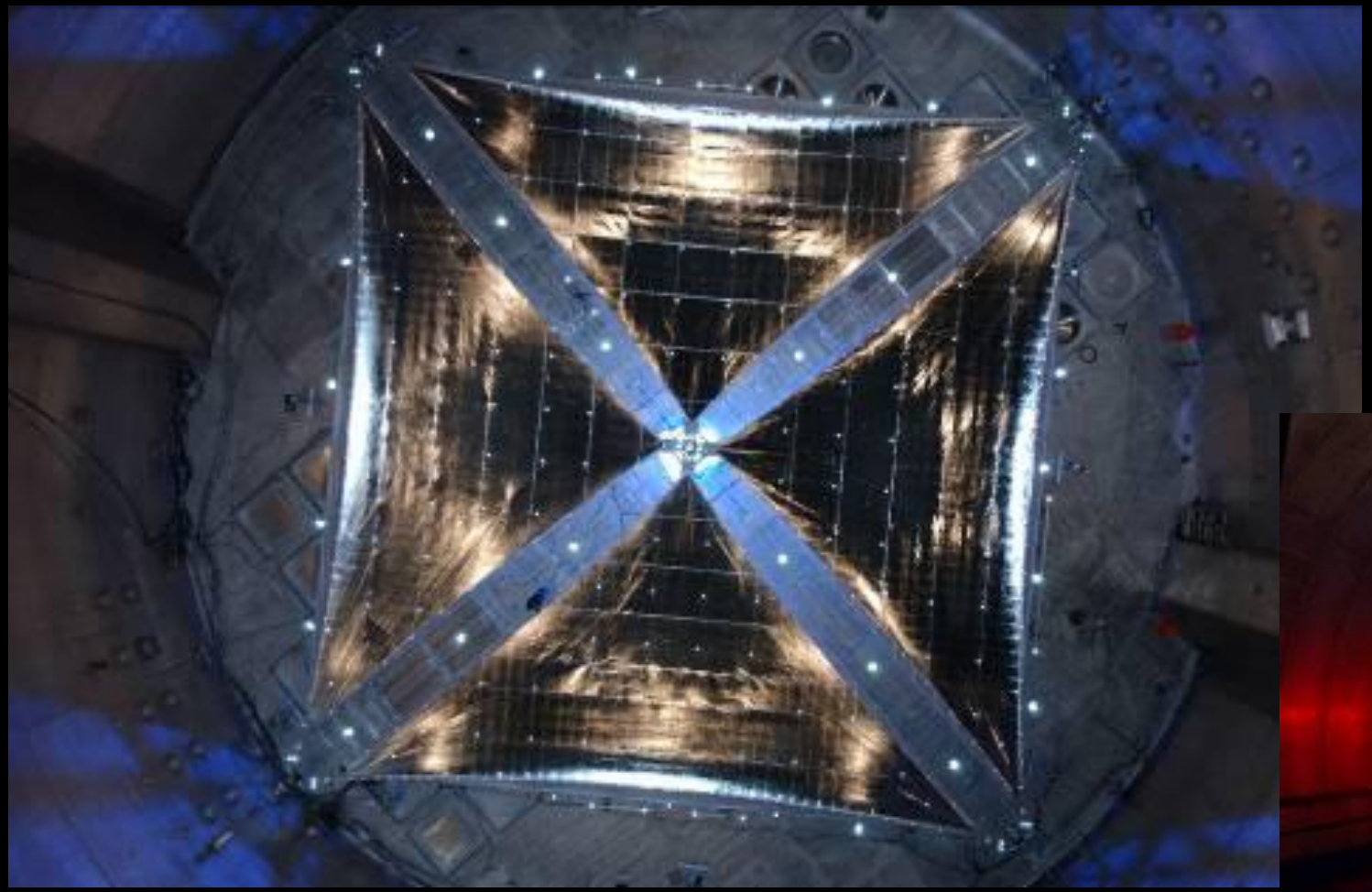


Shrinking orbit



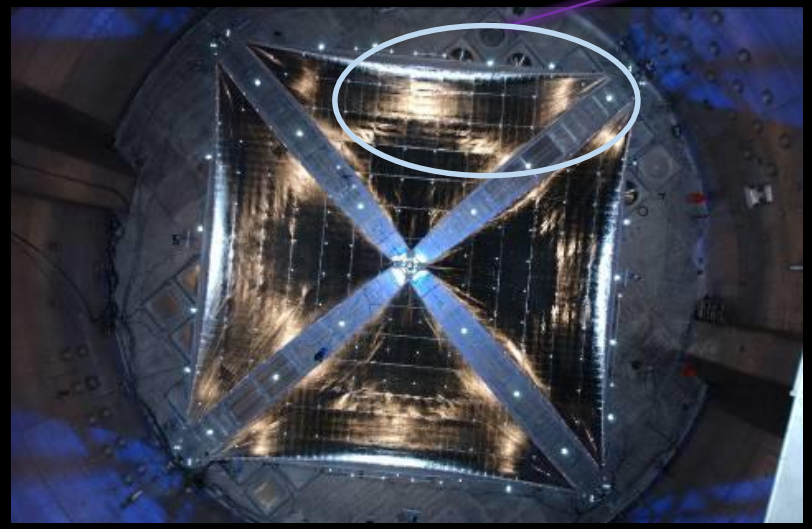
Expanding orbit

NASA Ground Tested Solar Sails



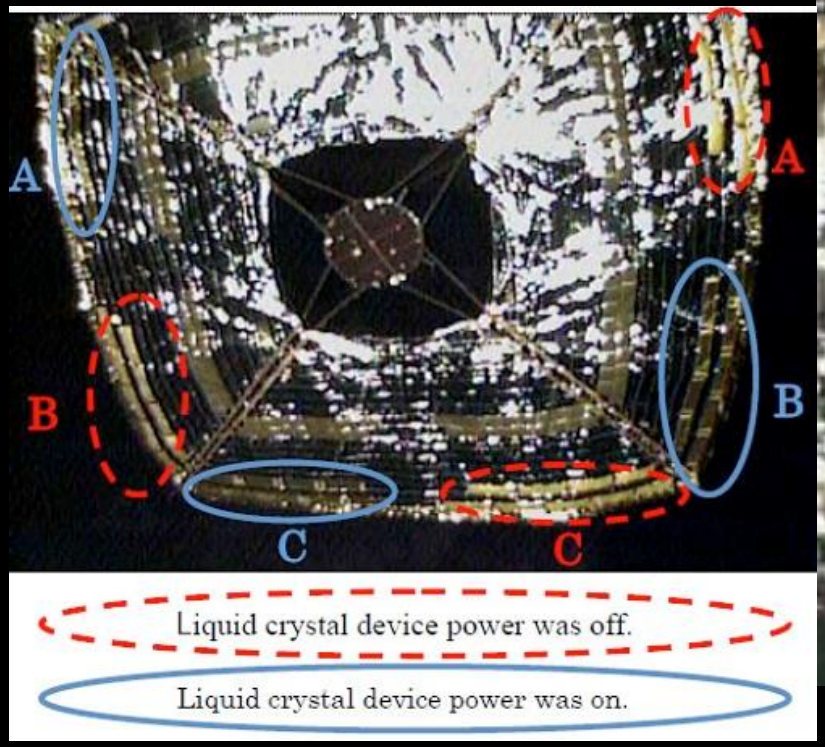
NanoSail-D Demonstration Solar Sail

- 10 m^2 sail
- Made from tested ground demonstrator hardware

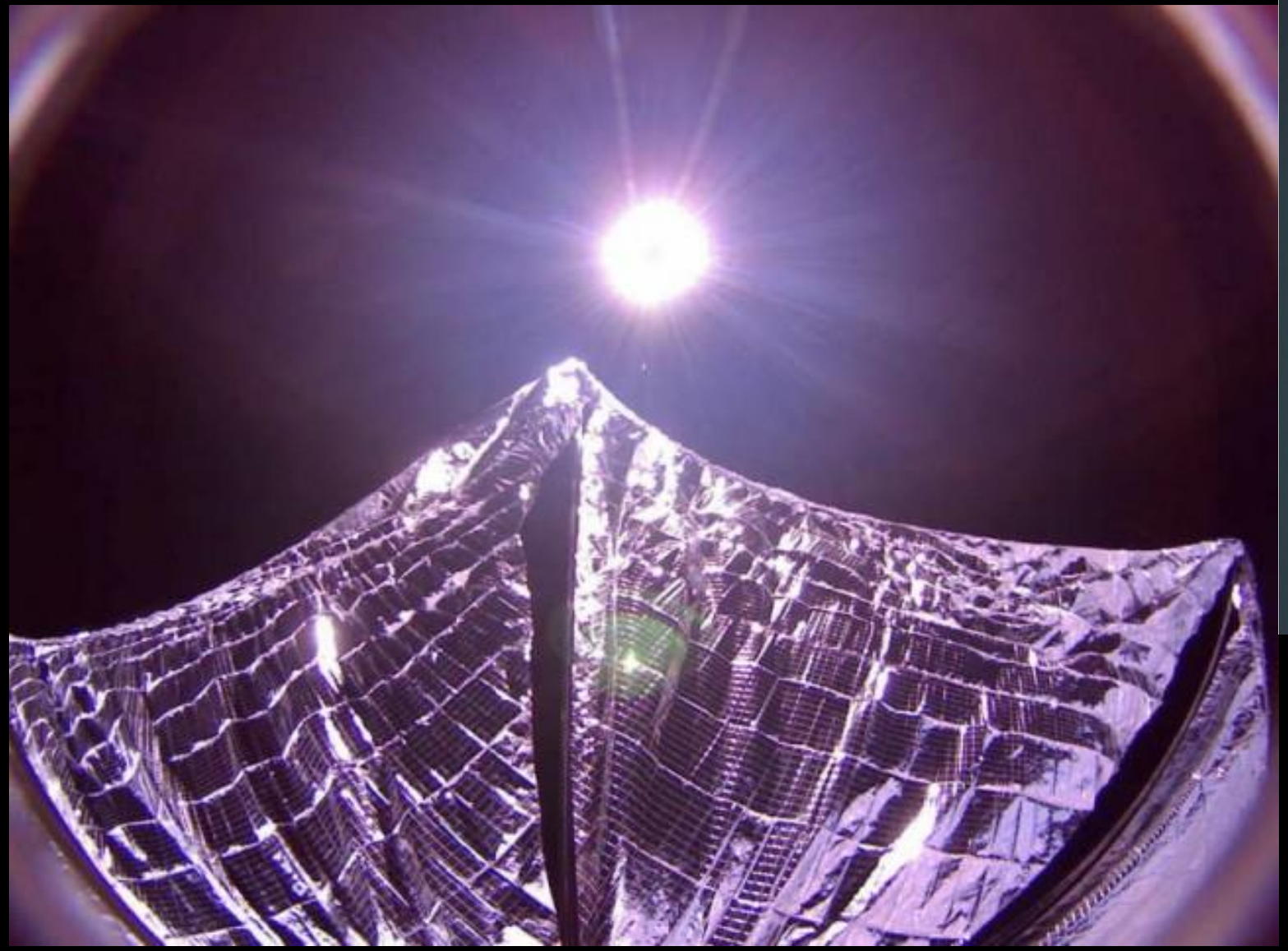


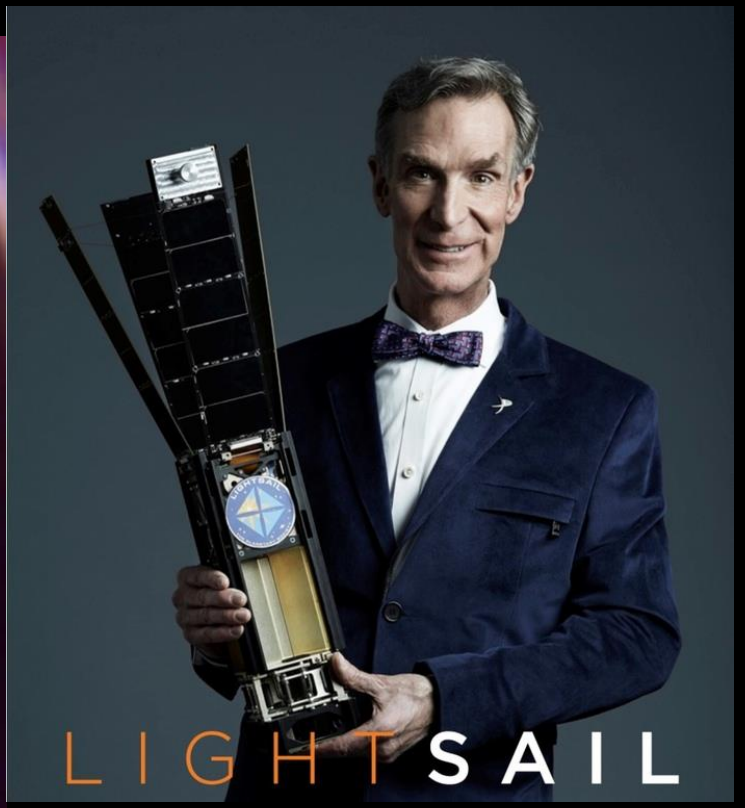
NanoSail-D in Flight

Interplanetary Kite-craft Accelerated by Radiation of the Sun (IKAROS)



The Planetary Society's LightSail-A

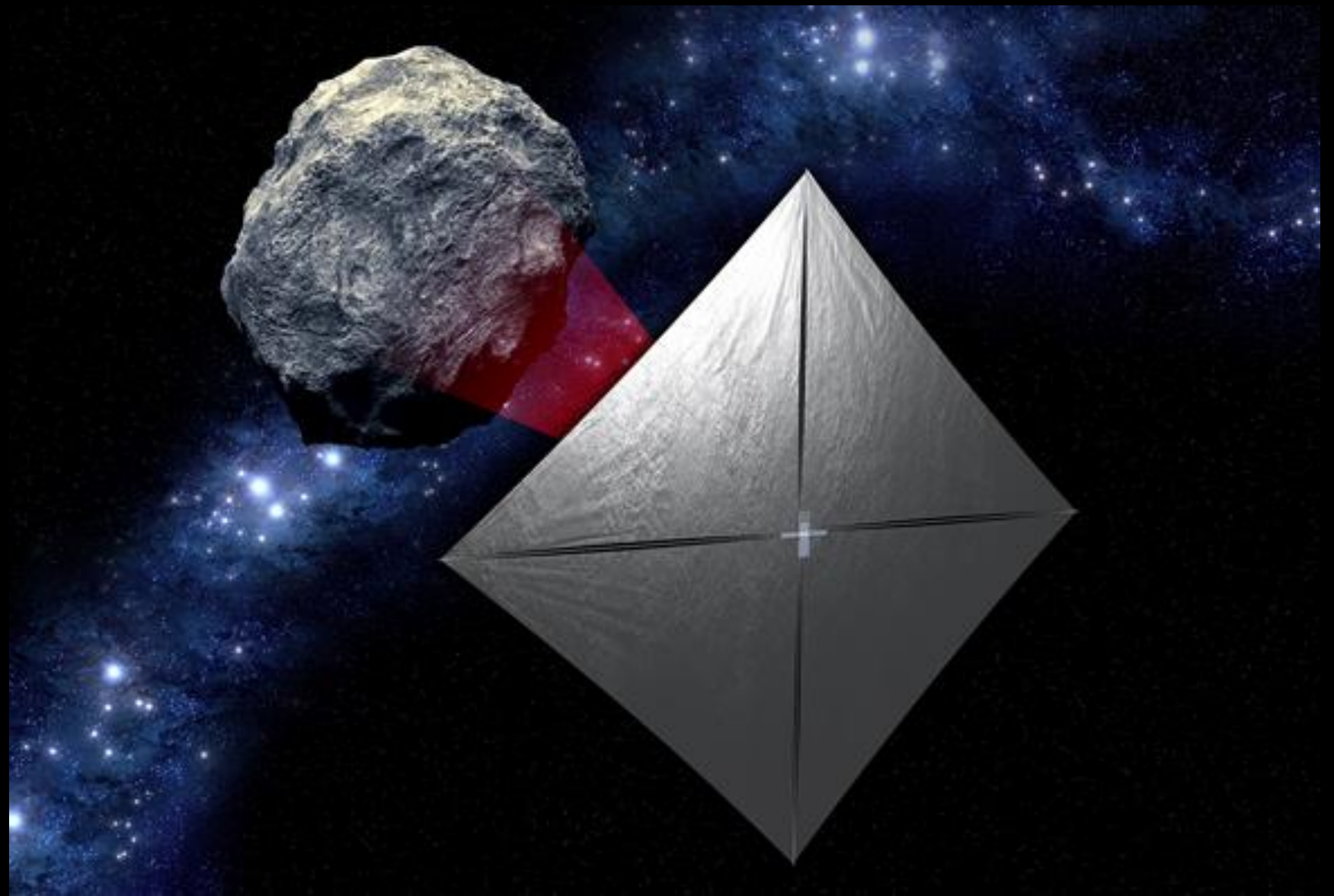




NASA and Solar Sails

- Solar Sails – What are they and how do they work?
- Planned Solar Sail Missions (NASA leading or partnering)
  - Near Earth Asteroid Scout
  - InflateSail
  - LightSail-B
- The BIG and Not-So-Secret Plan (Hint: Why we are at this symposium!)

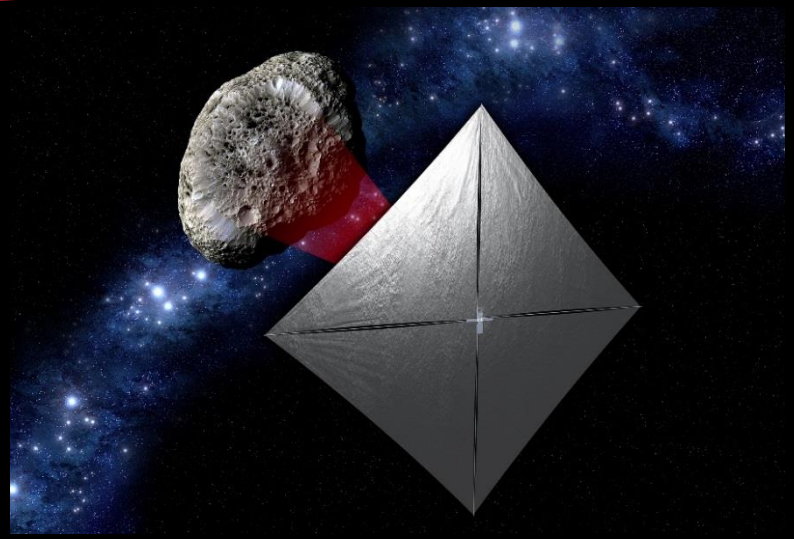
Near Earth Asteroid (NEA) Scout



Near Earth Asteroid Scout Overview

The Near Earth Asteroid Scout Will

- Image/characterize an asteroid
- Demonstrate a low cost asteroid reconnaissance capability



Key Spacecraft & Mission Parameters

- 6U cubesat (20 cm X 10 cm X 30 cm)
- ~86 m2 solar sail propulsion system
- Manifested for launch on the Space Launch System (EM-1/2018)
- Up to 2.5 year mission duration
- 1 AU (93,000,000 mile) maximum distance from Earth

Solar Sail Propulsion System Characteristics

- ~ 7.3 m Trac booms
- 2.5m aluminized CP-1 substrate
- > 90% reflectivity

NEA Scout Overview

Why NEA Scout?

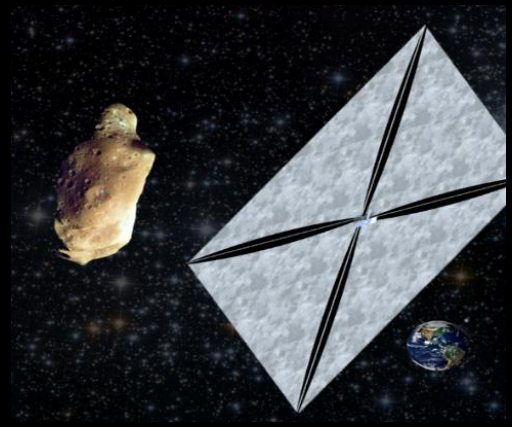
- Detect and track a Near Earth Asteroid (NEA) target
- Characterize the physical properties of the unresolved NEA target
- Flyby and characterize the physical properties of the resolved NEA target

Measurements: *NEA volume, spectral type, spin mode and orbital properties, address key physical and regolith mechanical SKG*

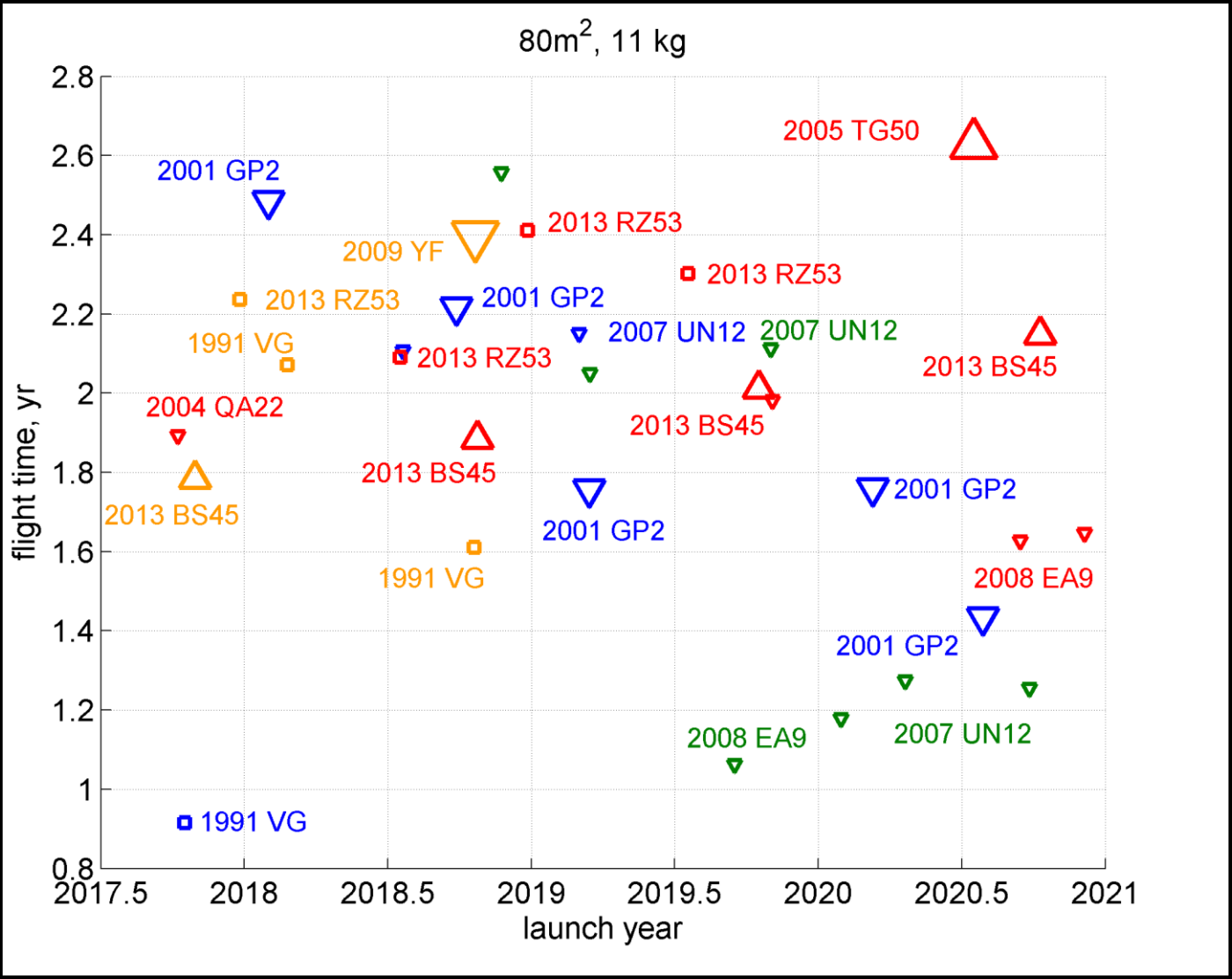
- ≥80% surface coverage imaging at ≤50 cm/px
- Spectral range: 400-900 nm (incl. 4 color channels)
- ≥30% surface coverage imaging at ≤10 cm/px

Key Technical Constraints:

- 30 month maximum mission duration
- Target must be within ~1 AU distance from Earth due to telecom limitations
- Slow flyby with target-relative navigation on close approach



Rendezvous Target Search

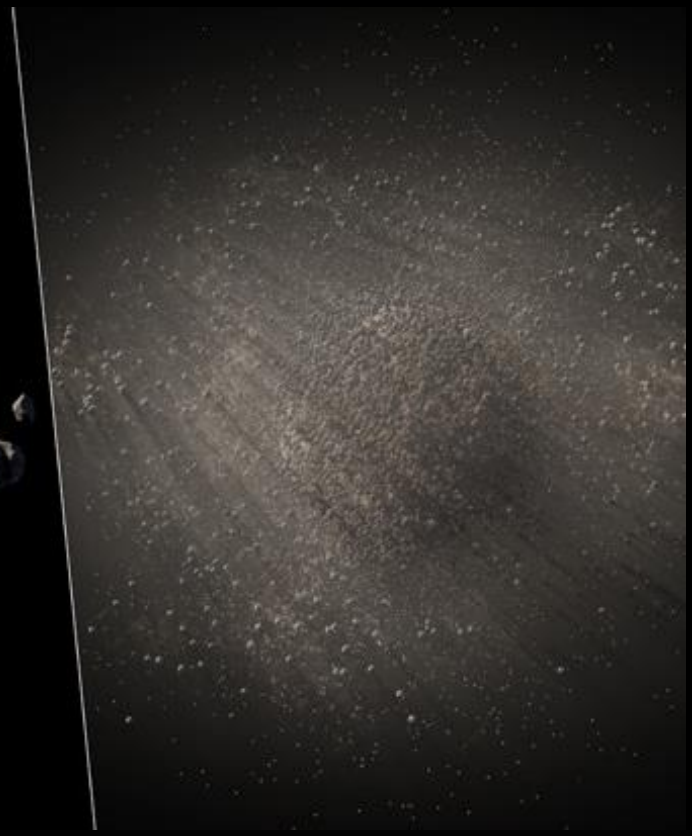


- **Telecom Distance (AU)**
  - **blue < .25**
  - **green < .5**
  - **orange < .75**
  - **red < 1**
- **OCC**
  - **△ under 2**
  - **□ under 4**
  - **▽ under 7**
- **Size (approximate diameter)**
  - **small < ~15 m**
  - **med. < ~30 m**
  - **large < ~50 m**

Local minima for flight time. Flight time increases linearly with pre-escape loiter time
Flight time increases non-linearly with delayed escapes

What do we Know About 1991 VG?

- Not much
- H = 28.4±0.7
- Diameter ~ 4-17 meters
- Albedo is unknown
- Rotation period between a few minutes and less than 1 hr.
- Unlikely to have a companion
- Likely did not retain an exosphere or dust cloud
  - Solar radiation pressure sweeps dust on timescales of hours or days



NEA Scout Operations Overview

MSFC Advanced Concepts

NEA

~10,000 km

<40 km

<1 km

Proximity

Data Downlink

Target Reconnaissance

Target Search and Approach

Lunar Fly-by 2+

Cruise

Lunar Fly-by 1

Separation from SLS

- ~1-2 additional lunar flybys to target departure
- Additional loitering possible for off-nominal launch dates
- Instrument calibration @Moon

- Minimum Ops, Periodic Tracking
- Spin Momentum Management
- Rehearsal of science activities

- Minimum science success criteria addressed

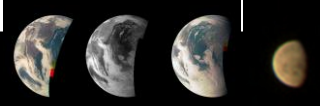
- At least one close, slow flyby (<10 m/s)
- Full success criteria addressed

- Sub-pixel imaging of target
- On-board image co-adding to achieve detection SNR
- Ephemeris and color addressed

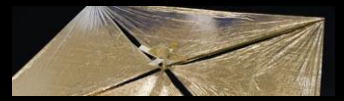
- <1 AU Earth dist.
- ~500 bps DTE (34 m DSN)
- On-board science processing

- De-tumble
- Initial Health Check
- ~10m/s dV to target 1st lunar fly-by

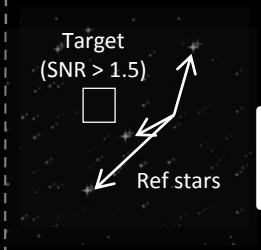
- Sail deployment
- Sail characterization
- Maneuver to 2nd lunar fly-by



Instrument Calibration

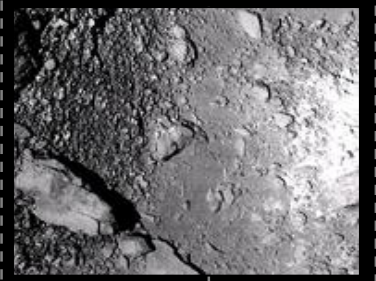


Sail Characterization



Target Scan Imaging (Image Stacking)

Imaging of the resolved target

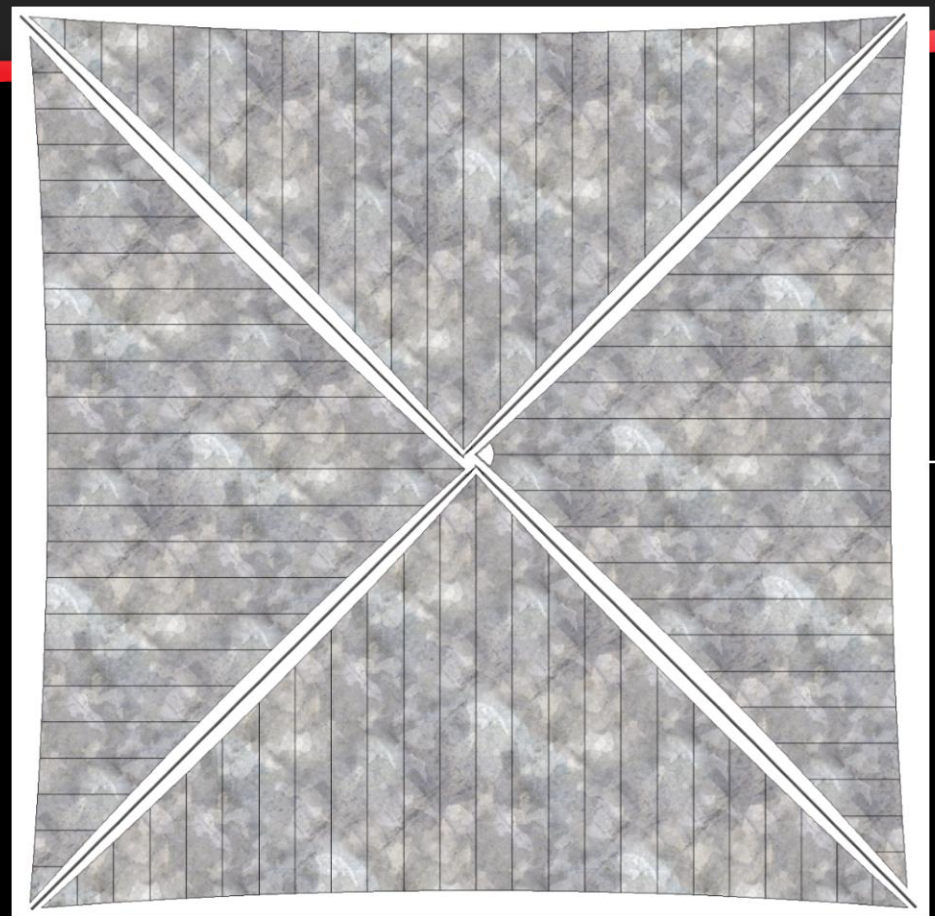


High Resolution Imaging (10 cm/pixel)

Deploy	Earth-Moon Departure	Cruise	Search/Approach	Recon	Proximity	Downlink

NEA Scout Approximate Scale

Deployed Solar Sail



6U Stowed Flight System

Folded, spooled and packaged in here

University of Surrey's InflateSail

InflateSail is an inflatable, rigidizable sail for flight in Low Earth Orbit:

- 3U CubeSat with deployed sail area of 10 m^2
- Sail supported by bistable booms
- Inflation is driven by Cool Gas Generators (CGG): low system mass, long lifespan

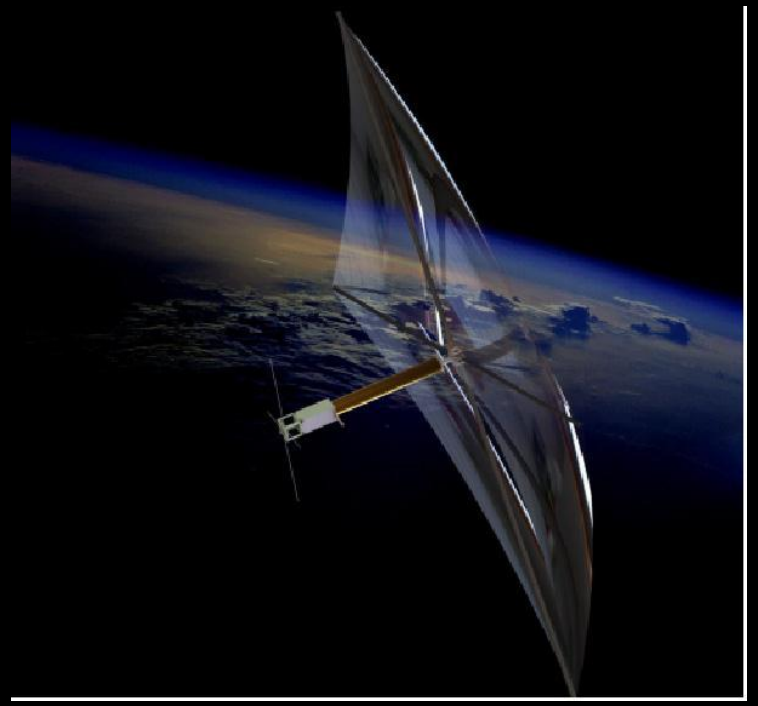
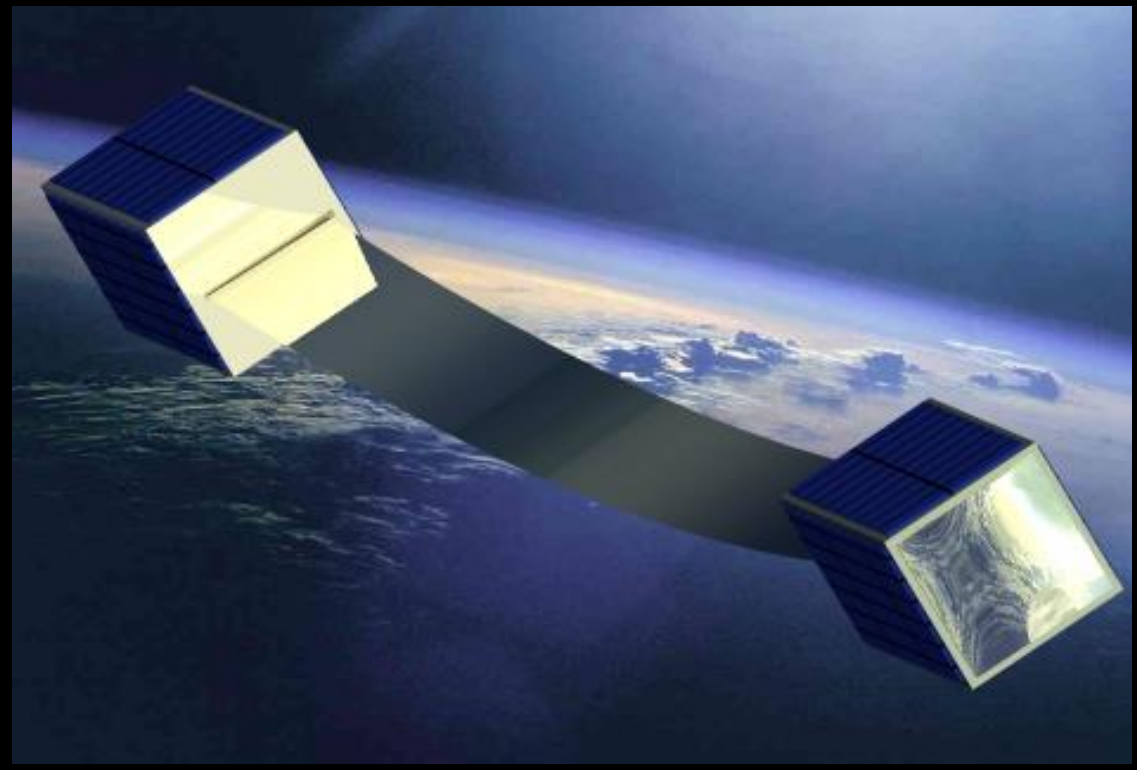


***Fig. 1**: InflateSail design concept*

***Fig. 2**: 80 mg CGG* George C. Marshall Space Flight Center

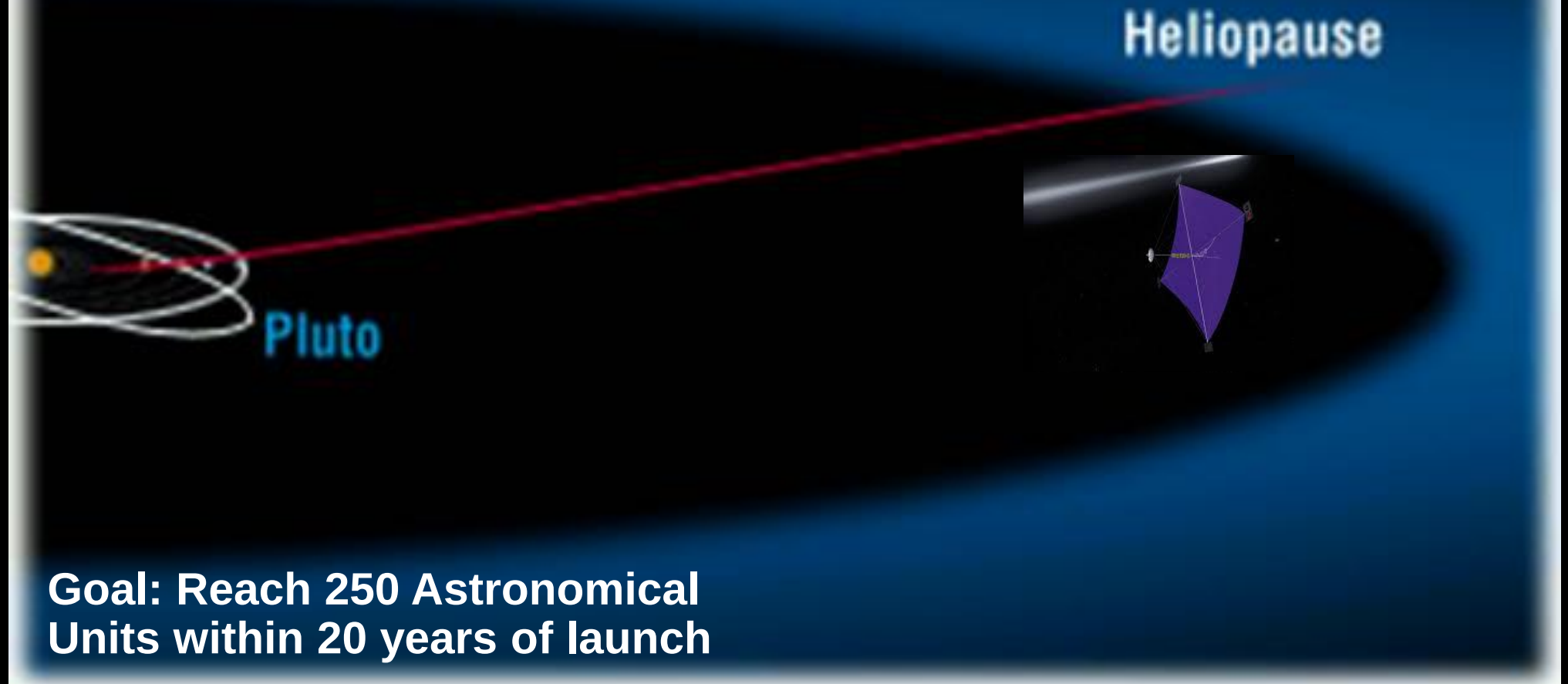
CubeSail CubeSat Solar Sail Propulsion Demonstration

- The University of Illinois at Urbana-Champaign (UIUC), working with NASA MSFC, NSF and CU Aerospace, built the flight hardware for a CubeSat-based 20 m^2 solar sail orbit raising demonstration mission
- Selected for flight under the NASA CubeSat Launch Initiative



Interstellar Probe: A Possible NASA Mission in the 2020's

Deploy a large (>10,000 m2) solar sail near the sun to enable travel 5X faster than Voyager

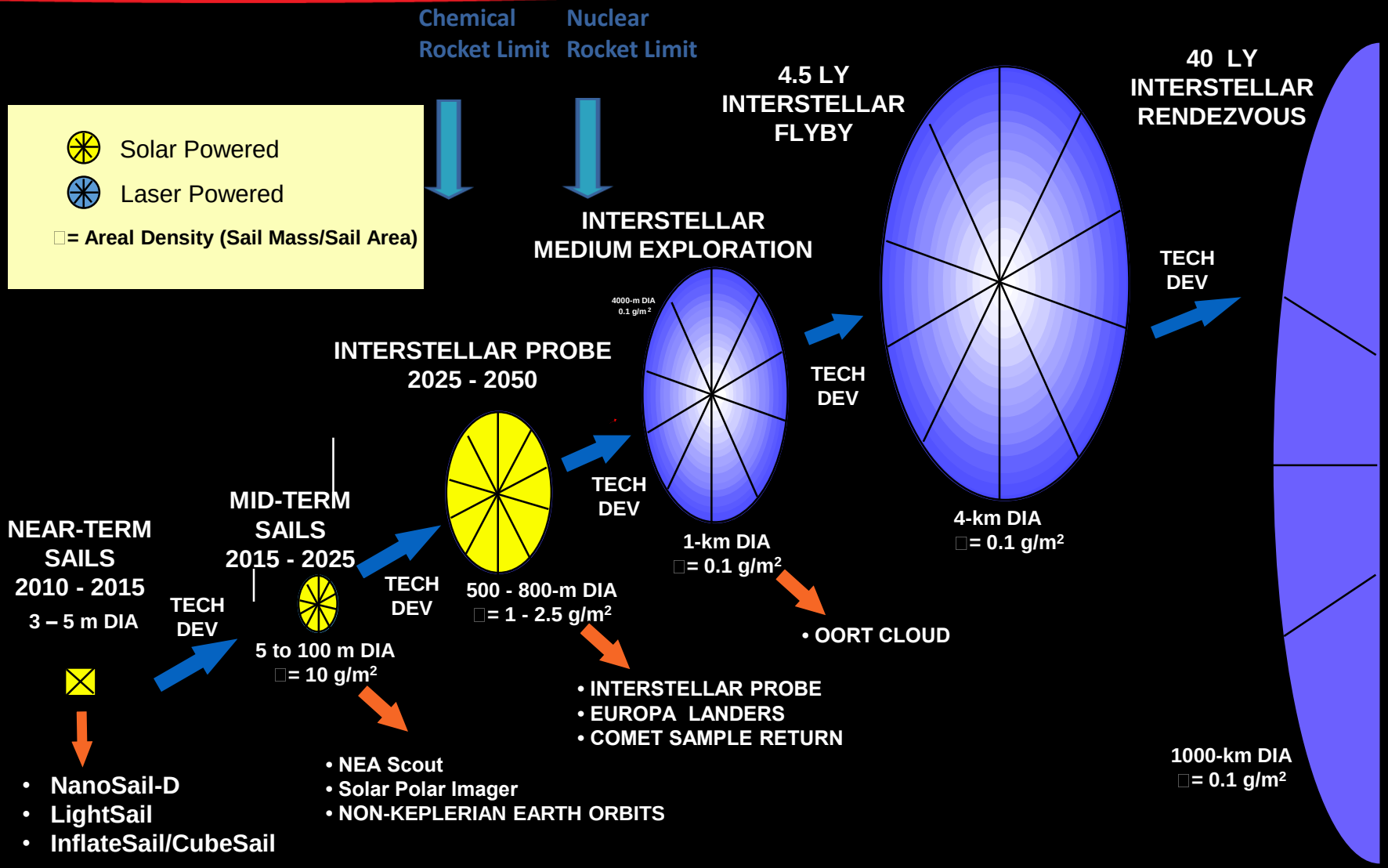


Goal: Reach 250 Astronomical Units within 20 years of launch

NASA and Solar Sails

- Solar Sails – What are they and how do they work?
- Planned Solar Sail Missions (NASA leading or partnering)
  - Near Earth Asteroid Scout
  - InflateSail
  - LightSail-B
- The BIG and Not-So-Secret Plan (Hint: Why we are at this symposium!)

The Real Reason to Develop Solar Sails



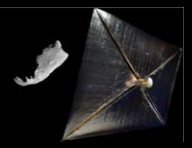
The Plan (as yet unfunded)

32 m^2

LightSail A/B
2015 / 2016

85 m^2
30 g/m^2 (sail system)

NEA Scout
ATP 2014
2017 – 2020



THE NEED

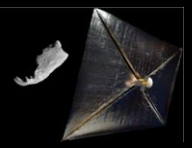
- Size: 10^6 m^2
- Areal density: ~< 3 $gram/m^2$

2015 2020 2025 2030

Aggressive Sail Development To Enable Interstellar Exploration

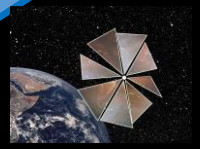
85 m2
30 g/m2 (sail system)

NEA Scout
ATP 2014
2017 – 2020



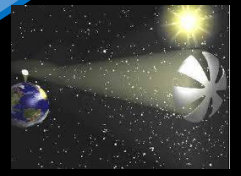
32 m²

LightSail A/B
2015 / 2016



Tech Demo 1
15 g/m² 2500 m²
Begin 2016
2019 Flight

Tech Demo 2
8 g/m² 25,000 m²
Begin 2019
2023 Flight



Tech Demo 3
8 g/m² 250,000 m²
Begin 2023
2027 Flight

Estimated Cost Per Demo $75M - $150M

2015 **2020** **2025** **2030**

Looking Back Toward Home